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Standing reserves of function: A Heideggerian reading of synthetic biology

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Abstract

Synthetic biology, an emerging field of science and technology, intends to make of the natural world a substrate for engineering practice. Drawing inspiration from conventional engineering disciplines, practitioners of synthetic biology hope to make biological systems standardized, calculable, modular, and predictably functional. This essay develops a Heideggerian reading of synthetic biology as a useful perspective with which to identify and explore key facets of this field, its knowledge, its practices, and its products. After overviews of synthetic biology and Heidegger's account of technology, I discuss calculability, utility, function, setting-upon, and ordering, with the aim of discussing the manner in which synthetic biology works to render the biological world as something *to be used*, rather than something that is *in and of itself*. Having developed this Heideggerian reading, I proffer a number of corrections to his account that enable a more accurate, nuanced understanding of synthetic biology. Specifically, I discuss the notion of *Ge-stell* and submit that multiple systems of 'enframing' may help to make Heidegger's argument more robust. I suggest that synthetic biology may work to reveal the natural world as a standing-reserve of function. I conclude with thoughts on precision and instrumentality.

Keywords: synthetic biology, Heidegger, function, calculability, enframing

Standing reserves of function: A Heideggerian reading of synthetic biology

1. Introduction

This essay explores synthetic biology—a developing form of biotechnology—through Martin Heidegger's account of modern technology. I employ a Heideggerian reading of the field in order to address a key ontological question: *how does synthetic biology—as a field of human practice—structure our understanding of and relation to the natural world?* My argument demonstrates that synthetic biology reveals living things as a standing reserve of function. My chief aim is ontological, though I submit a number of ideas on the place of Heidegger's framework vis-à-vis modern biological technologies. Overall, this piece presents a new case study, extends the application of Heidegger's work, and proposes a number of modifications to his argument about technology.

Heidegger's ontological explorations of technology are some of his most significant contributions to philosophical inquiry, both as a facet of his broader project on Being and as a separate philosophical undertaking. Heidegger is often credited as the first philosopher to address the ontology question regarding technology, and is likewise lauded as a founding figure of the philosophy of technology. Both these accolades are well earned—Heidegger's work on technology is challenging, innovative, and illuminative, despite some clear limitations.

Synthetic biology aims to be 'real' biological engineering. That is, its practitioners hope to make of biological materials a substrate for design and construction in a manner analogous to (or ideally, identical with) established engineering disciplines. I contend that Heidegger's arguments on the essence of modern technology, as well as its relationship to Being and humanity, are valuable for exploring the character of synthetic biology, its knowledge, its practices, and its products.

My argument contributes a philosophical exposition of synthetic biology guided by Heidegger's inquiry. After an overview of synthetic biology and a brief summary of Heidegger's discussion of technology, I explore the field through Heidegger's key concepts and arguments. Focusing on his discussions of calculability, utility, function, setting-upon, and ordering, I describe the manner in which synthetic biology works to reveal the biological world as something *to be used*, rather than something that is *in and of itself*. Next, I suggest a number of ways in which his analysis fails to explicate synthetic biology fully, and address those difficulties. Most importantly, I explore Heidegger's concept of *Ge-stell*, and suggest that biotechnology reveals natural things as a usable resource of function. Finally, I explore implications of my argument for future research.

2. Synthetic biology

Synthetic biology is constituted by an extensive and diverse population of scientific and engineering practitioners. 'The field' is not a unified discipline with consolidated agendas and practices; instead, 'the field' is an analyst's category. Here, I am primarily concerned with two modes of synthetic biological practice: first, that which seeks to construct predictably functional organisms in a systematic manner; and second, that which seeks to develop biological knowledge through the building of artificial biological constructs. In speaking of 'the field of synthetic biology' below, I refer to these forms of practice and knowledge. Research aimed at constructing proto-cells and attempts to develop minimal genomes are not of interest here.

The two forms of synthetic biology with which I am concerned employ similar concepts, practices, and epistemic and ontological positions. As I demonstrate, these guiding commitments follow an engineering logic. Thus, it is these foundational principles and activities which are the subject of my Heideggerian reading of synthetic biology. It is worthwhile summarizing these as a first step in bringing Heidegger's work to bear upon synthetic biology.

My argument establishes that synthetic biology premises (and promises) 'engineerable' nature. That is, its practitioners presume and argue that biological materials, entities, systems, and events can be modeled, modified, designed, and constructed in predictable, intentional ways. Biology is to serve as a substrate for engineering much as inanimate materials provide the base stuff for civil, mechanical, and electrical engineering. The practices and principles which underlie much of synthetic biological research are those of conventional engineering disciplines: abstraction of complexity (Endy 2005); standardization of design components (Arkin 2008); and modularity and decoupling of operational elements (Hartwell, *et al.* 1999; Endy 2005; Sauro 2008). Both in its aim *to build* as well as *to know*, a great deal of synthetic biology relies upon such principles. Biological systems are to be understood and modeled as if composed of functionally discrete, identifiable, and calculable modules, and those units are to serve as a basis for the construction of functional organisms. The epistemic-ontological position is clear: living systems can be analyzed, explained, and subsequently constructed as the physical and functional sum of their parts, much as electronic systems are understood and constructed. This position is not without controversy (see Kwok 2010), but its acceptance within synthetic biology is widespread. Arguably, it is this strict engineering outlook which distinguishes synthetic biology from earlier forms of genomics research (see Andrianantoandro, *et al.* 2006).

The broader ambitions of synthetic biologists—for instance, fully predictable construction of functional organisms—have yet to be satisfied. Nonetheless, it would be inappropriate to dismiss the field's accomplishments to date. Two examples illustrate both the field's achievements as well as its unsatisfied aims. Jay Keasling's laboratory at the University of California, Berkeley, employed *E. coli* and yeast to produce chemical precursors to the anti-malarial substance artemisinin (Keasling, *et al.* 2007). Keasling's group modified an existing organism and tasked it with a human-defined function—the production of a medical technology. However, the process of genetic transformation involved neither 'rational design' nor 'predictable functionality'—two key aims of synthetic biology. The project succeeded through a laborious process of trial-and-error most often associated with metabolic pathway engineering. A second example is that of Michael Elowitz and Stansilas Leibler's so-called 'repressilator' (2000). This construct, composed of three transcriptional repressor systems and a fluorescent reporter, functioned to induce oscillatory behavior in *E. coli*. Each bacterium with this system periodically produced green fluorescent protein, effectively glowing in a time-dependent manner. Elowitz and Leibler's aimed to explore natural time-dependency and oscillatory behavior by constructing an artificial system with comparable properties. While such synthetic oscillators have a number of potential applications, the effort is an exemplar of *knowing through building*. As with the Keasling group's artemisinin-precursor-producers, the 'repressilator' demanded a great deal of trial-and-error work. The project did not consist of the straightforward process of design and construction towards which many synthetic biologists direct their aims. The 'messy' nature of these examples does not detract from their final achievements; it simply serves to remind observers of the field that 'rational' design and construction are *aims*, rather than *accomplished realities*.

The engineering principles and practices underlying such aims—standardization, modularity, rational design, predictable functionality—characterize synthetic biology. These principles and practices I explore below in order to subject them and the wider field to a Heideggerian reading. Broadly, synthetic biology's guiding principles suggest a crucial fact about this emerging field: *synthetic biology aims to be an engineering discipline; it hopes to be in the business of making technological things.*

3. Heidegger on technology

Given the space constraints and my overall objective here, I cannot provide an exhaustive articulation of Heidegger's thought on technology. Here is simply present an overview. After all, this is not a study *of* Heidegger; rather it is a study *with* Heidegger of synthetic biology. Clearly, any summary is necessarily limited. I direct readers interested in dedicated exegeses of Heidegger to examine the list of works cited below. The present discussion is one focused on synthetic biology.

3.1 Heidegger on technology

Heidegger aims throughout his ontological investigations of technology to identify and characterize the *essence* of technology. His project rests not with *ontic* matters—those primarily concerned with technological things as contrivances—but rather with *ontological* issues. To wit, he poses the following question:

> We ask the question concerning technology when we ask what it is. (QCT: 4)[1]

Heidegger argues that an 'instrumental', or 'anthropological', definition of technology represents it as simply an employable means towards an end, and offers no possibility of

[1] Primary works by Heidegger are referenced with acronyms as follows: *Being and Time* (BT), *Introduction to Metaphysics* (IM), *Discourse on Thinking* (DT), 'The question concerning technology' (QCT), 'The age of the world picture' (AWP), 'Science and reflection' (SR), 'The thing' (TT), 'Modern science, metaphysics, and mathematics' (MSMM).

arriving at an understanding of technology's essence[2]. Hood summarizes the distinction between instrumental and ontological as follows:

> For Heidegger, to conceive something in its *ontic* dimension means that one grasps how it is related to other entities, but to conceive something in its *ontological* dimension is to appreciate how it is related to Being, to appreciate exactly how Being makes this entity possible. (Hood 1972: 353, my emphasis)

That is, Heidegger is concerned with technology's relationship to Being. He wants to explore how technology comes to 'presence'—comes-to-be—in the first place, and why it presences in the particular manner in which it does.

This is precisely what 'essence' means to Heidegger. 'Essence' is not a set of characteristics that bind together tokens of a type class; rather, 'essence' refers to the manner in which things-which-are come to presence for us. Essence is manifested in presencing—the way in which everything around us is made intelligible within an "ordered and meaningful structure of experience." (Feenberg 2005: 2). This provides the fundamental link to Being, which can be understood as "the ongoing manner in which everything that is, presences." (Lovitt 1982 [1977]: xv)

For Heidegger, the difference between the kind of presencing made possible by ancient *techné* and that of modern technology characterizes two fundamentally distinct ways of making artefacts and understanding the world. Feenberg summarizes the point as follows:

> Heidegger maintains and emphasizes the contrast between ancient *techné* and modern technology… These are the two chief forms of making and, correspondingly, the two chief modes of revealing. (2005: 25)

Heidegger argues that *techné* is a form of *alétheuein*—generally translated as 'revealing'. *Alétheuein* also means 'truth' for Heidegger. Thus, *techné* is involved in a form of human artifice that renders things intelligible in such as a way that they are revealed in their true selves. A craftsperson making a vase is involved in a process of ushering and nurturing the thing into existence. By contrast, the revealing associated with modern technology is a challenging-forth. The world is made intelligible following the utilitarian demands of the technological system. Heidegger's notable example of a hydroelectric dam and power station is instructive here. The power station affects the manner in which the river in intelligible to us:

> What the river is now, namely, a water-power supplier, derives from the essence of the power station. (QCT: 16)

[2] For Heidegger, only dedicated exploration of technology's essence can free us from the dangerous, obliging relationship that characterizes our interaction with technology. See Dreyfus 1997.

The essence of technology, at work in the relationship between the power station and its environment, is manifest in how the river is rendered intelligible. This form of revealing, a challenging-forth of nature that renders it intelligible as raw material for human utility, is characteristic of modern technology. Heidegger terms this revealing *Ge-stell*.

Conventionally, *Ge-stell* is translated as 'enframing', which captures two key facets of the concept: first, the notion that *Ge-stell*, as a revealing, makes the world intelligible within a specific set of constraints; second, that this form of revealing reduces the entities brought forward to a mere 'skeleton' (or 'frame') of their actual existence. The constraints Heidegger identifies are the "exigencies of planning and control." (Feenberg 2005: 25); the reductive presencing of things means that there is no "unmediated access to things freed of their usefulness." (Glazebrook 2001: 377) *Ge-stell* enframes the world as raw material for human utility, as that which can be subjected to the planning, controlling, and using activities of humanity. Zimmerman writes that *Ge-stell is*:

> … a one-dimensional way of disclosing entities as raw material, a disclosure which provokes humanity to behave in accordance with the technological imperative of infinitely expanding production for its own sake. (Zimmerman 1990: 348)

Put otherwise, *Ge-stell* reveals the actual as the usable, and things are rendered intelligible as stuff to satisfy human needs and amenable to human control. Heidegger argues that this form of revealing renders nature as a 'standing reserve'[3] for human utility. This standing reserve Heidegger often characterizes as a storehouse of energy:

> Nature becomes a gigantic gasoline station, an energy source for modern technology and industry. (DT: 50)

To follow the earlier example, the river is intelligible as a source for hydroelectric power. It is 'set upon' by technology as a repository of usable resources. Its existence as a river *qua* river is suppressed; the river is instead revealed as a substrate for human technological ends.

Thus, Heidegger understands the essence of technology to rest with its capacity to affect the manner in which things are rendered intelligible to us *as usable for our technological ends*. It is fundamentally a mode of Being which discloses "all beings whatsoever as objective, calculable, [and] quantifiable" (Zimmerman 1977: 75). *Ge-stell*—the essence of modern technology—is a form of rendering things around us as intelligible in a particular way. I contend that synthetic biology makes the living world intelligible as a standing-reserve of function.

[3] The German *Bestand* is generally translated as 'standing reserve'. Rouse suggests that *Bestand* describes that which is "standing on call" (1985: 81). Ultimately, the concept refers to resources of which humanity may avail itself.

In brief, Heidegger argues that the essence of modern technology is a mode of Being, a manner in which things are rendered intelligible. This mode of Being is *Ge-stell*, a revealing of things which imperiously forces them to appear to us as calculable, orderable material for our use. The world is revealed as a standing reserve for our employment and consumption.

3.2 Making use of Heidegger's argument

My choice of Heidegger's analysis of modern technology rests on a number of considerations. First, there are currently no studies from the philosophy of technology that address the ontology question regarding synthetic biology. As such, I find it a useful first perspective to employ Heidegger's work, given his place and prominence within the development of philosophical studies of technology. Second, my interest in the manner in which synthetic biology works to render living things intelligible in particular ways is fundamentally compatible with Heidegger's project in ontology. Heidegger's engagement with Being and beings rests precisely on how the former constitutes the basis upon which the latter are rendered intelligible. Third, the issues that he identifies as central to the study of modern technology—such as quantification, utility, ordering, and standardization—are all key facets of synthetic biological practice. My engagement with this field suggested that his work was best suited to address these topics.

Nonetheless, Heidegger's work is not without its constraints and complications. Those which I view as most problematic to my argument here—his focus on the physical sciences and his monolithic conception of *Ge-stell*—are addressed in section 5. Three other issues—the novelty of anthropocentric functionality, Heidegger's romanticization of earlier human practice, and his notion of 'authentic' being—are discussed in critical asides in section 4.

4. A Heideggerian reading of synthetic biology

My aim is an ontological exposition of synthetic biology that follows Heidegger's studies on modern technology. I intend to demonstrate that synthetic biology renders the living world intelligible as a standing-reserve of function. To do so, I address six facets of synthetic biological practice: the emphasis placed upon rendering nature as calculable and quantifiable; the primacy of function and use in the manipulation of natural systems; the making and re-making of ontological distinctions between natural and artifactual entities; the harnessing of natural phenomena as a prototypical case of 'setting-upon'; the use of standardization to displace uniqueness and unmanageability; and the relationship between *physis*, *poiesis,* and modern technology in synthetic biology. In exploring each topic through Heidegger's thought, I address this essay's central concern: *the manner in which synthetic biology structures the intelligibility of natural entities and phenomena.*

4.1 The primacy of calculability

For Heidegger, *Ge-stell* discloses all beings as calculable entities—that is, as beings susceptible to objective quantification. This manner of revealing entities is characteristic of modern science (AWP, TT, MSMM), and forms the foundation for the making and use of technological things (QCT). In being rendered intelligible as a constellation of quantifiable objects and occurrences, nature is also disclosed as a resource for human disposition. In synthetic biology, principles of calculability are ubiquitous, and provide great insight into the constitution of the field, its practices, and its practitioners' aims.

As I noted above, synthetic biology is comprised by scientists and engineers practiced in many different disciplines. These include—but are not limited to—biology, chemistry, physics, computer science, and any number of engineering fields. The population of engineers in synthetic biology is considerable, and alongside physicists, this constituency has contributed to the nascent field a focus on calculation, quantification, and engineering-based thinking. The single most distinguishing feature of synthetic biology—that which might differentiate it from other applications of genetic engineering techniques—is the discursive and practical emphasis upon engineering principles and concepts (see Heinemann & Panke 2006). Undoubtedly, this phenomenon is a consequence of the field's composition. The migration of an engineering optic into the field of biological science and technology underlies the primacy of calculability in synthetic biology. It also lends credence to Heidegger's argument that *Ge-stell* makes beings intelligible as quantifiable and exploitable entities.

Quantification is a core concept in engineering practice, and is of vital interest to synthetic biological practitioners. While measurement and quantification of biological phenomena and occurrences remain monumental problems for the field, there exist early attempts to develop measurement units and guidelines (e.g. Canton, Labno, & Endy 2008). In order to quantify the transcriptional process, units such as PoPS and RiPS have been proposed. Respectively, these are acronyms for Polymerase Per Second and Ribosomes Per Second. These proposed units have been discussed in a variety of ways by practitioners (e.g. Chopra & Kamma 2006; Arkin 2008; Purnick & Weiss 2009), but their use is broadly symbolic. Nonetheless, the key philosophical point concerns the zeal for calculability. PoPS and RiPS are biological analogues to electrical current in an electronic system, and while imperfect, they satisfy a scientific and technological drive for quantification and measurement.

A related, supremely important component of Heidegger's argument concerns the ontological reality of that which is *not* quantifiable. Heidegger argues that science and technology allow only for that which is calculable and orderable. Beings presence as calculable entities; those which cannot be rendered in calculable or orderable forms are dismissed or omitted. This has bearing for synthetic biology in relation to physicalism and vitalism. The former position holds that biological processes and phenomena are ultimately wholly explainable in terms of quantitative physical theory; the latter attributes to living organisms qualities not susceptible to physical explanation. Vitalism in its strongest iteration advocates for the existence of a *vis vitalis*; in more moderate forms, it simply rejects the premise that physical laws are capable of accounting for all biological phenomena. Many synthetic biologists reject both vitalist and anti-reductionist arguments on the same ground (e.g. Nature Editorial Board 2007; Yeh & Lim 2007). Namely, that such stances amount to little more than mysticism, and are wholly unscientific. The proper scientific perspective is based in quantification. Following from their commitment to engineering-based thinking and a drive towards calculability, practitioners admit no explanations that provide for biological phenomena irreducible to physical explanation. Heidegger writes:

> That which is, is only that which, when correctly thought, stands up to correct thinking. (IM: 207)

Put otherwise, the theoretical and experimental basis of a particular science will determine what is an appropriate view of the world, as well as how beings are rendered intelligible. Synthetic biology can structure what is understood to be real—that which 'is'. As Rouse writes:

> Only what can show up within the [scientific] procedures by which we achieve a 'proper perspective' on the world is real. (1985: 80)

For synthetic biology, the proper perspective—theoretical and experimental—is one that depends upon physical quantification. Physicalism does not simply refuse to admit particular arguments: it denies to non-calculable entities and phenomena their existence. That which is not calculable is not accepted; that which is not quantifiable is not real. The result is a dismissal of countless entities and phenomena that cannot be quantified with existing techniques, but that are important aspects of living things nonetheless.

In summary: the essence of modern technology is in part defined by a drive to calculability and quantification. Such a drive affects how natural entities and phenomena are rendered intelligible. Those facets of them that can be quantified are intelligible; those that cannot are omitted.

4.2 Function, use, and value

Calculability and usability are complimentary concepts in Heidegger's thought. Thus, for something to 'presence' as a calculable entity is for that same entity to become involved in a system of order and use. Heidegger argues that technology reveals the natural as exploitable raw material for human manipulation. Purpose is attributed where none existed previously, as the "meaning and purpose of things is something we create, not something we discover." (Feenberg 2005: 12) Technology reveals nature as something *to be used*.

Function and purposefulness are supremely important concepts and aims within synthetic biology. This is particularly the case for synthetic biologists working to develop predictably functional organisms. Currently, a number of projects are underway to develop organisms capable of human-defined functions. These include producing biodiesel (Savage, *et al.* 2008), fixing nitrogen from the atmosphere, targeting and destroying cancerous cells (Anderson, *et al.* 2005), and storing information (Ajo-Franklin, *et al.* 2007). These projects are not proof-of-principle exercises. Fundamentally, these are engineering endeavors aimed at creating technologically-functional biological systems.

Practitioners often describe their intention as that of creating organisms 'for useful ends'. Clearly, synthetic biologists concerned with designing and building functional organisms are making of natural entities purposeful objects.

A first critical aside is warranted at this point. Heidegger associates anthropocentric functionality and value with *Ge-stell*. Natural things are rendered intelligible as resources for our use. However, natural entities during the Greek and medieval periods may have just as easily been framed in such terms. After all, milk cows, race horses, and pets all serve anthropocentric ends—consumption, entertainment, and companionship—and all predate the rise of Heidegger's modern technology. Functionality is not novel. However, I believe that in the case of synthetic biology, Heidegger's argument stands. Unlike previous human practices with living systems, this field attempts to incorporate the *predictability* of engineering design and fabrication. As I will discuss further below, this is clearly a modern phenomenon, and distinguishes between the kind of broad functionality of milk cows and race horses, and the predictable engineered functionality of modified *E. coli*.

The making of functional organisms is consistent with Heidegger's account of technology. Moreover, the desire to construct *predictably* functional organisms brings to mind his argument that calculability and usability are unavoidably linked to humanity's will to mastery. Predictability in synthetic biology implies control. To render biological systems predictable in the same manner as that of conventional products of engineering—for instance, electronic circuits or automobiles—is to engage in the imposition of certainty. Perhaps more lucidly: in order for biological systems to be controllable, they must be predictable; predictability demands certainty. The demand for certainty is central to engineering practice (see Vincenti 1990). However, unpredictability is often described as one of the defining empirical characteristics of living entities. Synthetic biology must temper organisms' propensity towards unpredictability in order to satisfy its aim of predictable functionality.

The drive for technological reliability—in the form of predictable functionality—is an unequivocal display of humanity's will to mastery. Unpredictability is a distinguishing characteristic of living entities. Synthetic biologists often argue that this is an illusory problem: *we simply don't know enough yet*. Nonetheless, this supposition is rarely challenged; even the possibility of inherent unpredictability is disregarded as unscientific[4]. Within the confines of synthetic biology, unpredictability is a problem to overcome. Heidegger writes:

[4] Quantum mechanics' focus on probability, rather than complete determinacy, is often employed to challenge this facet of Heidegger's argument. Nonetheless, quantum mechanics also implies that only what has been measured can be known, thus lending credence to Heidegger's argument that human metrics are the basis for what is real (See Glazebrook 2000, Ch. 5). Ultimately, my focus is synthetic biology, not quantum physics, so the point is only of tangential interest.

> The will to mastery becomes all the more urgent the more technology threatens to slip from human control. (QCT: 5)

This may be read as indicating that as a technology's recalcitrance grows, so too does the human will to master it. Biology is difficult to control; biological technologies correspondingly resist the type of predictive functionality expected of modern technologies and celebrated as a goal for synthetic biology. As a result, the will to mastery is heightened within this field. Unpredictability—the empirically real—must give way to predictability—the desired useful. In itself, this transition is indicative of technology's emphasis upon the exploitable over the actual, a topic I discussed above. Here, the transition is less important than the methods by which it is being undertaken.

In summary: Technology renders beings as useful. To be technologically useful, such beings must display predictability. Making natural entities predictable is considerably difficult. Heidegger argues that in such cases, the will to control is stoked. Thus natural entities and phenomena are rendered intelligible as things to dominate or tame.

4.3 Setting-upon

For Heidegger, the revealing enabled by modern technology is a bringing-forth that sets-upon. Put otherwise, modern technology is responsible for rendering things intelligible in such a manner that nature is subordinated to human endeavors and forced to yield itself as resource. Modern technology does not make use of nature's products in a manner that respects natural limitations; it does not harvest products that bring themselves about. Rather, it forcefully draws these products from nature, compelling natural entities to provide beyond their ordinary capacities. Nature is set-upon insofar as the dictates of human practice determine the productive capacity of natural entities. Heidegger also refers to this setting-upon as a *challenging*.

Heidegger's key example in illustrating this challenging is that of cultivation and agriculture. Whereas ancient forms of agriculture respected the limitations of plants, modern technological agriculture orders, forces, and exhausts nature. He writes:

> The field that the peasant formerly cultivated and set in order appears differently than it did when to set in order still meant to take care of and maintain. The work of the peasant […] places seed in the keeping of the forces of growth and watches over its increase. But meanwhile even the cultivation of the field has come under the grip of another kind of setting-in-order, which *sets upon* nature. It sets upon it in the sense of challenging it. Agriculture is now the mechanized food industry. (QCT: 14-15, emphasis original)

The 'mechanized food industry' forcefully compels nature to yield ever-increasing quantities of product, with limited regard for the natural limitations of plants. The history of cultivation is a trajectory increasingly away from overseeing and caring towards greater ordering and coercing.

A brief detour is warranted here. Heidegger's arguments about setting-upon, and particularly his claims about agriculture, may appear to be unjustified romanticizing of the past. This critique is valid, but I believe that his point still holds. Industrial agriculture is different from smaller-scale subsistence farming. When the social, political, and economic contexts of such practice change—as they have over the thousands of years of human cultivation—so too does our relationship to the objects of those practices. That's the key point. Industrialization changes our understanding of cultivated plants. Engineering practices—born in the late 19th century—may similarly change our understanding of living things through synthetic biology.

Many projects in synthetic biology fall under the category of chemical production. Biological organisms are particularly adept at making chemicals, and this capability has been and is being harnessed in the making of valuable substances. The Keasling group's work resulted in organisms capable of producing chemical precursors to artemisinin—a valued anti-malarial drug. Ongoing work in the same laboratory aims to do the same for biodiesel. Living entities' capacity to construct chemicals, as well as the relatively low cost of employing self-reproducing colonies of microscopic organisms instead of laborious chemical synthesis, are two factors responsible for this focus in synthetic biology.

Creating microbial chemical-producers broadly demands two steps. First, organisms must be modified to produce the required chemical. This often involves so-called metabolic pathway engineering, and is generally the more difficult of the two steps. The Keasling lab's work with anti-malarial drugs was onerous, time-consuming, and expensive. The second task in this type of synthetic biology is the 'fine-tuning' of a modified organism to increase yield and maximize efficiency. Put otherwise, an organism capable of producing the required chemical must also be optimized to produce the highest possible output with the lowest possible consumption of feedstock and energy. This second component concerns both the viability of the entity as well as the cost-effectiveness of the system.

This form of synthetic biology 'sets-upon' nature in two ways. First, organisms are rendered intelligible as nothing more than microbial chemical factories. They are physically and functionally tasked with the making of chemicals generally foreign to the natural variants of the organism. Such chemicals may even be toxic to 'wild-type' strains. The products harvested are not those that come into being as a result of natural and unforced processes; rather, they are the result of intentional changes to the organism. Second, in order to maximize yield, natural regulatory mechanisms are generally disabled or transformed. Like the mechanization of cultivation, here the harvesting is not respectful of natural limitations. It is a coercive challenging-forth. Organisms do not naturally bring forth their products; they are modified following the dictates of human necessity and in accordance with engineering standards and practices[5].

[5] Put otherwise, living things are transformed into things of human artifice with human-specified functions. C.f. Author, forthcoming, for an extended discussion of this particular issue.

In summary: Technological functionality and control are not deterred by natural limitations. Within synthetic biology, living entities are set-upon, challenged, and brought-forth as components of a productive technological system. They are rendered intelligible as things to be exhausted of their products.

4.4 Orders of nature and artifice

Every issue discussed above relates to ordering. Calculability is a form of setting-into-order; functionality requires an order of practice within a technological system; setting-upon is not simply a coercive drawing-forth of resources—it is also a forceful setting-into-order. Throughout Heidegger's writings on technology, ordering plays a central role in defining not simply the essence of modern technology, but also our relationship to technological *things* themselves. Heidegger's discussions on equipment (BT), things (TT), science (AWP), mathematics (MSMM), and technology (QCT) all depend on an understanding of revealing as ordering.

As noted above, the revealing associated with modern technology, *Ge-stell*, is a superficial presencing of things. Nature is revealed as a standing-reserve for human disposition. Technological systems challenge nature forth as nothing more than raw material. The scientific optic—a product of the essence of technology—similarly represents things in a manner distinct from their authentic being, as entities orderable under a scientific rubric. These two facets of revealing as ordering—technological and scientific—result from the same essence of technology, but are manifested differently.

In discussing the scientific optic, Heidegger considers the case of a jug filled with wine (TT). Seen through the perspective of science, the wine filling the jug is perceived through physical concepts of states of matter. Heidegger writes:

> In the scientific view, the wine became a liquid, and liquidity in turn became one of the states of aggregation of matter, possible everywhere. We failed to give thought to what the jug holds… (TT: 169)

Stated simply, that which makes wine distinct *qua* wine is suppressed. Wine as a unique thing is concealed by universal and universalizing laws of physical science, or rather, its authentic being is never given the opportunity to come forth into presencing. Glazebrook offers a similar example in noting that the physics of falling objects does not distinguish between a falling apple and a falling bomb (2000).

Synthetic biology presents a similar case. That form of synthetic biology concerned with developing biological knowledge attempts to develop models and descriptions of intra-cellular activity, from the workings of individual genes to the interaction of proteins to the movement and growth of the entire organism. The current state of knowledge and the considerable complexity of natural entities and processes force such scientific work to rely on a great deal of simplification. Complex behaviors are 'black-boxed'; simplifying assumptions are put into place. Such practices are employed in the hope of developing successful models, simulations, and descriptions. Read through Heidegger's argument, such practices obscure and obstruct the self-presencing of microscopic organisms much as states of matter obfuscate wine *qua* wine. Organisms are reduced to chemical interactions; complex living entities become simplified vessels of molecular activity. The living thing *as a living thing* is replaced by a diagrammatic understanding of events and scientific objects.

Heidegger's notion of revealing as an ordering also concerns the bringing-forth of nature as a standing-reserve. *Ge-stell* is fundamentally a constraining and imperious revealing that brings nature forth as resource for human consumption. The river becomes a source of hydroelectric power; the soil of the field a resource for the mechanized food industry. Similarly, synthetic biology brings forth natural organisms as resources for various technological systems—for instance, as sources of chemical compounds for the biomedical industry. Moreover, organisms themselves are revealed as technological objects; that is, not as standing-reserve, but as *instrumenta*.

In summary: The essence of modern technology involves setting beings into particular orders. This kind of structuring underlies the manner in which things are rendered intelligible. For synthetic biology, such ordering follows the scientific principles that characterize physicalist studies of living things, as well as the technological expectations made of genetically-modified organisms.

4.5 Standardization

Heidegger argues that modern technology reveals nature as an orderable, manageable, disposable substrate for human enterprise. Above I addressed calculability, control, setting-upon, and ordering as facets of human technological practice in synthetic biology. Yet another aspect of Heidegger's argument is that of order as management. In the challenging-forth that reveals nature as standing-reserve, beings are incorporated into a system of technological management.

Consider Heidegger's example of a tract of land challenged-forth as a deposit of valuable minerals. The earth is revealed as a deposit of employable substances such as coal and ore. The coal drawn from such a tract is produced, shipped, stored, and eventually used to generate electrical power—it is "on call" within a technological system (QCT: 15). That system encompasses an industry of monumental scope, comprised by mining technologies, shipping and storing facilities, electrical generating stations, distribution networks for electrical current, the vast assortment of tools and contrivances that make use of that electricity, and the instruments needed to register and bill for power consumption. It is a system designed to regulate, manage, and use the resources drawn from the tract of land in a determinate manner. The hydroelectric station is fundamentally part of the same system, with modifications allowed for a different form of generating power. Nonetheless, those differences are in a great many ways irrelevant. The output of both power stations is measured in the same manner; the demands placed upon the distribution network are the same; the use and billing of that electricity is identical. The fundamental differences between land and river are suppressed—both are standing reserves of energy.

Lovitt and Lovitt argue that Heidegger stresses the equalization of natural entities within technological systems. Idiosyncrasy is difficult to manage; that which conforms to set standards is predictable. As such, technology "suppresses uniqueness and promotes indistinguishablity" (Lovitt and Lovitt 1995: 242). Heidegger suggests that the standing-reserve is 'objectless' (QCT: 19). That is, when things are revealed simply as resources for human use, as standing-reserve, they are deprived of their unique existence as distinct beings (Glazebrook 2000). *Ge-stell* strips objects of their 'objectness' and reveals them as simply that-which-can-be-used. Once again, the actual becomes the usable. Several of synthetic biology's key aims precisely focus on achieving this anonymous uniformity.

Much of synthetic biology actively works to standardize biological phenomena. Following conventional engineering practices regarding standard, interchangeable components and modular construction, synthetic biologists have attempted to develop biological analogues to standardized nuts and bolts. So-called standard biological 'parts' are discrete segments of DNA intended to serve specific purposes. 'Parts' are *in theory* physically and functionally discrete modules for genetic construction. They may serve to initiate genetic transcription (promoters), end such transcription (terminators), or act as signaling devices for scientific experimentation (reporters). Of most fame are 'BioBricks', developed and stored at MIT's Registry of Standard Biological Parts. These display limited modularity and functional isolation, although as a whole 'BioBricks' display much of the same context-dependence characteristic of biological processes. The newly-established BIOFAB aims to categorize, refine, and standardize many of these existing 'parts', as well as develop new technologies for making biology modular (Sanders 2010). This drive for uniformity is designed to improve the reliability and predictability of genetic constructs, as well as simplify the design process. Making biology manageable requires tempering nature's characteristic idiosyncrasy.

In summary: Technology suppresses the individuality of beings. Instead, it subordinates entities to the use they serve. Within synthetic biology, this entails that natural entities are deprived of their inherent idiosyncrasy in order to make them standardized and manageable beings. They are rendered intelligible as interchangeable and uniform.

4.6 Physis, poiesis *and modern technology*

Much of Heidegger's work on technology directly addresses the relationships between *physis*, *poiesis*, and modern technology. This topic is vitally important to studies of studies of synthetic biology. Zimmerman summarizes Heidegger's use of *physis* and *poiesis* as follows:

> *Physis* names the self-generating bringing-forth of living things, but also names the presencing by virtue of which such things comes into appearance within a world… The name for *physis* in human existence is *poiesis*: the disclosiveness (art in its broadest sense) which makes bringing-forth (producing of all kinds) possible." (Zimmerman 1990: 234)

Physis is self-revealing—the uncompelled bringing-forth of things. The blooming of a rose is an example of *physis*, which is ultimately the "bursting forth of a thing out of itself" (Lovitt 1973: 47). *Poiesis* is the intentional human revealing of things—as Zimmerman notes, 'art' in the broadly-encompassing sense of human production. Heidegger emphasizes that authentic *poiesis* is humble and assistive[6]. The sculptor provides the opportunity and carries out the nurturing needed for the sculpture to reveal itself from the block of marble. Disingenuous *poiesis* is invasive and forceful revealing; its epitome is *Ge-stell*. *Ge-stell* compels entities into revealing themselves as manageable resource for human utility. Synthetic biology presents a compelling tension. It employs living entities—those which are self-revealing through *physis*—to accomplish technological ends—those which involve the invasive challenging-forth of modern technology.

Heidegger views *physis* as the most authentic form of revealing. The self-exhibiting of say, a rose in bloom is the most authentic manifestation of Being. In *physis*, things are most accessible *as themselves*. That which is real "is what presences as self-exhibiting" (SR: 167). The undisturbed existence and multiplication of microscopic living entities is precisely this form of self-revealing. The imperious challenging-forth of technology stands oppossed to this uncompelled presencing. Again, the river is not permitted to presence *as itself*, but rather is rendered intelligible as a storehouse of employable energy; it is challenged-forth from what is real to what is usable. Comparably, the objects of synthetic biology—those studied, conceptualized, and fabricated—are compelled into a modern technological revealing, rather than allowed to self-presence in *physis*. Despite the myriad difference between living things and technological objects, nature is subjected to an engineering optic. Living things are rendered intelligible as what we want them to be, rather than existing as what they are. The intelligibility of things contingently rests upon the mode of revealing of different practices. The sculpture's *poiesis* reveals differently than does the *Ge-stell* of modern technology.

Another critical deviation is necessary here. Heidegger's discussion of *physis*, *poiesis*, and modern technology presents the notion of authenticity of being. Authenticity is a particularly problematic concept, but it is also unnecessary to making use of Heidegger's work. The real issue is how any given human practice—here, synthetic biology—renders things intelligible. Heidegger argues that modern technology imposes anthropocentric utility upon the world to the exclusion of all else. My argument is similar. Synthetic biology renders living things as objects to be used. Authenticity is not needed as a concept. What matters is that synthetic biology imposes a particular, contingent way of structuring our understanding of and relation to living things.

In summary: Heidegger argues that modern technology suppresses the natural coming-into-being of things, instead imposing a utilitarian being on the world. In subjecting

[6] While it may be possible to argue that *poiesis* is synonymous with craft practice, I do not believe that this craft practice is of the kind found in scientific research. Moreover, synthetic biologists explicitly advocate a move away from craft to 'real' engineering.

natural things to an engineering optic, synthetic biology renders them intelligible as things humans can *use*. *Ge-stell* frames such natural things as resource.

4.7 A Heideggerian reading of synthetic biology

This essay addresses the manner in which synthetic biology structures the intelligibility of natural entities and phenomena. I have argued the following: synthetic biology renders things as quantifiable and dismisses that which is not calculable; it enframes things within expectations of utility; it makes entities intelligible as limitless resources; it orders things following anthropocentric aims and values; it suppresses natural idiosyncrasy and imposes artificial uniformity; and it mobilizes an engineering optic to understand its products. In brief, synthetic biology renders living systems intelligible as things *to use*, rather than simply things *in and of themselves*.

5. Revisiting Heidegger's account

A Heideggerian reading of synthetic biology offers much but also makes evident a number of his argument's limitations. Resolving these difficulties may improve my exposition of synthetic biology, as well as prove helpful in evaluating the applicability of Heidegger's work within contemporary discussions of technology.

5.1 Physics, biology, etc.

Heidegger's arguments about calculability, utility, and the standing reserve, as well as his account of technology more broadly, are based upon the claim that physics underlies the technological enterprise. He writes:

> … [modern technological revealing] concerns nature, above all, as the chief storehouse of the standing energy reserve. Accordingly, man's ordering attitude and behavior display themselves first in the rise of modern physics as an exact science. (QCT: 21)

For Heidegger, modern physics is "the herald of Enframing" (QCT: 22), and without the exacting quantification employed by the physical sciences, *Ge-stell* is not possible.

A narrow focus on physical science is defensible if technology is understood *only* in the context of such disciplines as chemical, mechanical, or electrical engineering. Synthetic biology aims to be and might one day become the biological analogue of these engineering fields. As such, a Heideggerian reading of synthetic biology demands a consideration of the biological sciences.

As I establish above, synthetic biology draws practitioners from a broad constellation of sciences and engineering disciplines. Predictably, a large number of these individuals have backgrounds in the biological sciences or biology-focused research. Biology is a fundamentally different science than physics (see e.g. Mayr 2004), and many of Heidegger's claims about the latter—such as the drive towards calculability—are not applicable to the former. Nonetheless, in studying biological *engineering*, the distinct character of biological *science* is less relevant than it might appear to be.

Above, I describe the manner in which principles and practices from conventional engineering disciplines are mobilized within synthetic biology. Concepts such as standardization, modularity, and calculability are clearly important to this developing field. While the biological sciences matter greatly, biological knowledge is read through the core principles of engineering disciplines whose basis is found in the physical sciences. Unifying much of synthetic biology is a commitment to the use of an engineering optic. This optic is the most suitable focus for a Heideggerian analysis. The issues above concerning calculability, functionality, and utility stem from the precepts of such an engineering-based understanding of the natural world.

Heidegger's thought fails to acknowledge and engage with the multiplicity of sciences and engineering practices represented in synthetic biology—as well as countless other contemporary technical and scientific fields. Ignoring vital differences between say, civil and biological engineering obscures the character of each field, its chosen materials, and the objects produced from those substrates.

5.2 Ge-stell(s)

For Heidegger, Being is "that which makes the beings of the world accessible and intelligible to us" (Zimmerman 1977: 75). It makes possible our understanding and experience of that-which-is-real—it is "the reality of the real" (*Ibid*.: 76). Importantly, Being is not historically-invariable. The manner in which ancient *techné* revealed the world differs substantially from the *Ge-stell* of modern technologies. Heidegger attributes this difference to a change in humanity's relationship to Being.

Ge-stell is a challenging-forth that reveals the natural world as a standing reserve for human utility. This form of revealing must be understood in the context of Heidegger's focus upon the physical sciences. Revealing the natural world as a quantifiable, manageable, and useful reserve depends upon the precepts and practices of modern physics, which for Heidegger is intimately bound up in the essence of modern technology. For the present argument, Heidegger's insistence on a single, defining form of revealing is limiting. Might we not insist on the possibility of various forms of enframing? I believe this question can be addressed in two ways.

The first approach employs the context dependence and historical contingency of Being. In 'The question concerning technology', Heidegger proffers an analysis of modern technology based upon the character of modern physical science. A contemporary use of Heidegger's work might instead focus on the development and use of modern biological science and biological technologies. After all, Heidegger's arguments on technology were formed prior to the postulation of the double-helix structure of DNA, and *a fortiori* the growth of molecular biology. New science and new technologies might betoken a new relationship to Being.

Perhaps synthetic biology presents humanity with a novel ontological condition, one enabled in virtue of this particular technological practice. While this approach may offer some insight into the ontological question of synthetic biology, I believe it presents a number of unacceptable difficulties. Most importantly, such an argument is unsatisfactorily simplistic. Equating a new science with a new mode of Being postulates a straightforward, linear relationship between science and our understanding of the world. However, Being is broader than just one type of scientific practice. Moreover, giving to synthetic biology the power of radically transforming our relationship to Being grants too much importance to a collection of practitioners lacking the kind of coherence found in other scientific and technical disciplines. As such, not only does this answer misrepresent synthetic biology, it affords the field with unwarranted influence over ontological matters.

A second approach to resolving this issue focuses not on the changing face of Being, but rather on Heidegger's concept of *Ge-stell*. Contrary to the monolithic *Ge-stell* Heidegger proposes, I suggest one that encompasses various modes of enframing. Glazebrook posited a similar approach vis-à-vis science and technology:

> The *Ge-stell* of technology is standing-reserve—beings appear as resource. The *Ge-stell* of science is objectivity—beings appear as object. (2000: 241)

Of course, utility and objectivity are interrelated. For instance, calculability is preeminent in both. Nonetheless, modern science and modern technology reveal the world in ways unique to each practice. Glazebrook's keen observation suggests a useful elaboration of the concept of *Ge-stell*. Technological and scientific fields differing in their composition may also differ in their revealing of the natural world.

5.3 A standing reserve of function

Heidegger characterizes *Ge-stell* as a challenging-forth that reveals the natural world as a standing reserve, to be employed and managed by the human technological enterprise. He characterizes this standing reserve with various examples, including those of a hydroelectric power station, a mechanized farm, and an airplane sitting on the tarmac. These examples share a common feature: modern technology reveals each as use-potential. I posit that while *Ge-stell* is a revealing that renders natural things as objects for human utility, the specific manner of each rendering depends upon the character of the technology in question. *Ge-stell* is not monolithic. It is a complex arrangement of modes of revealing. Each mode is a contingent phenomenon, characterized by the particularities of any given scientific or technological practice.

Synthetic biology does not reveal the world as a standing energy reserve in the manner that Heidegger often attributes to modern technology. Although there exist multiple projects aiming to develop fuel-producing bacteria (Savage, *et al.* 2008), characterizing these as attempts to make of the natural world a source of energy does little for our understanding of synthetic biology. Such a representation would be inapplicable to the majority of projects currently underway in the field, such as those pursuing 'smart' therapeutic organisms (e.g. Anderson, *et al.* 2005) or biological memory (e.g. Burrill &

Silver 2010). The unifying characteristic of these endeavors, and the result of an engineering-based approach to biological research, is to reveal the natural world as a reservoir of technological functions[7].

Function is hugely important within synthetic biology. Practitioners within the field routinely speak of 'harnessing natural functions' or 'developing novel functions' (McDaniel & Weiss 2005). Existing biological capacities are modified in order to render desired outcomes, or foreign capacities are transferred via recombinatorial techniques into target organisms much to the same end. In either circumstance, genetic material is altered in order to develop a desired technological function. For instance, a particular metabolic pathway may be transformed in order to produce a chemical the organism would not normally assemble on its own. Such a process would make of the cell a microscopic assembly mechanism. Alternatively, genetic material may be taken from an organism and transferred into another in an attempt to supplement the latter with new capacities. In this way, practitioners can develop naturally-inexistent but technically-desirable combinations of biological processes.

Additionally, the use of engineering precepts within synthetic biology favors a reduction of living things to functional characterizations. The desire to 'discover' and develop biological modularity is based upon a confidence that organisms can be divided into functionally-discrete components. This is evident in practitioners' emphasis on units of genetic material, rather than the encompassing organism. The latter is often abstracted away, or portrayed as fully reducible to the activity of its genes. Not only are organisms then rendered as collections of modules that 'do' different things, but they are also revealed as potential sources of functions useful for the making of biological technologies. If nature is modular, and biological capacities can be transferred for the sake of human utility, then the natural world is a stock of potentially-exploitable functions. This stance is sufficiently pervasive that one prominent synthetic biologist speaks of developing a registry of biological functions to catalogue and manage these capacities.

Heidegger argues that *Ge-stell* renders the world as objectless uniformity in the guise of a stock of usable resource. The standing reserve of function does precisely this for living things. In reducing biological organisms to the capacities of their biological processes, the distinguishing features and unique being of varying life forms are suppressed in favor of a totalizing homogeneity. Tellingly, a speaker at the recent Fifth International Meeting on Synthetic Biology argued that a *defining characteristic* of the field is that it does not see or care about boundaries between species (Voigt 2011). It is not concerned with differences, he stated. Rather, it looks out onto the natural world and pays attention only to what it can *use*. There do not exist living things; rather, there exist functions, which are transferable without limitations. This form of enframing is not mentioned by Heidegger, but its ramifications are fundamentally similar, in that the natural world is revealed as something to be used. The modality of *Ge-stell* proposed here enables a more robust and faithful ontological account of synthetic biology.

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[7] Note that my focus here is *technological* function, rather than *biological* function. In other work, I explore the connection between these concepts within synthetic biology.

6. Final considerations

A number of considerations merit attention intriguing consequences of my analysis. These issues are critical in developing an understanding of synthetic biology—both with the aid as well as independent of a Heideggerian reading—and consequently deserve dedicated arguments outside the scope of the present discussion.

The first consideration is that of calculability without precision. Synthetic biology's commitment to a systematic engineering-based approach in part rests on practices of measurement and quantification. However, continuing attempts to effect such quantification have met a number of difficulties, including technical limitations, practical difficulties, the character of the target objects, and a field of practitioners increasingly wary of claims to calculability. Many researchers in synthetic biology now believe that their brand of quantification must allow for much broader tolerances than are generally accepted in other natural sciences or established engineering disciplines. Strictly speaking, then, not calculability *without* precision, but rather calculability with *liberal precision*. This view is by no means dominant, nor does it necessarily represent an acceptance of biological uniqueness; rather, it seems to be an acknowledgement of the current state of knowledge and technical capacities. Nonetheless, such acquiescence is representative of broader difficulties synthetic biology has encountered in studying, modeling, and constructing biological systems. It also indicates a pressing will to quantification that may suffer setbacks while remaining fundamentally undeterred. Last, it suggests that this engineering field has yet to consolidate its design parameters and performance standards—a key step in the development of novel engineering knowledge and practice (see Vincenti 1990)

The second consideration relates to the revealing of nature as both standing reserve and *instrumentum*. Synthetic biology reveals a standing reserve of function. However, synthetic biology presents an interesting case insofar as the things of the natural world are rendered both as stock for human utility *and* as technological contrivances. In Heidegger's examples, the *instrumentum* is always of human fabrication. The dam and power station are human-built objects imposed upon the river, which is subsequently revealed as a source of energy for human consumption. The contrivances of synthetic biology are produced from the same organisms rendered as a standing reserve of function. Thus, it is crucial to keep in mind that the products of synthetic biology—synthetic biological artifacts—are of the same initial character as the reservoir of function their design, construction, and use reveal. Synthetic biological work ultimately does distinguish between tools and resources, but these cannot be divorced as easily as can be the human-built hydroelectric system and the river into which it is built.

Last, the standing reserve of function I posit suggests a direction for future philosophical work on synthetic biology. Given the nature of synthetic biology's target substrate, the philosophy of technology would be well advised to enter into dialogue with the philosophy of biology. By bringing 'function' to the fore, my argument suggests one potentially useful link between these fields. 'Function' is a key concept for both the philosophies of technology and biology. Navigating the multiple accounts of the concept within each field may suggest ways to develop a nuanced, robust philosophy of synthetic biology.

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